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A Study of a 60 Horse-Power Suction Gas Producer, using Anthracite Coal

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A STUDY OF A 60 HORSE-POWER SUCTION GAS PRODUCER, USING ANTHRACITE COAL

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED A STUDY OF A 60 HORSE-POWER SUCTION GAS PRODUCER, USING ANTHRACITE COAL.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE

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TEST OF A SUCTION GAS PRODUCER.

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The constantly increasing use of gas producers in the last few years has resulted in a popular demand upon the part of producer manufacturers and power consumers for a fuller knowledge of the scientific principles underlying the operation, care, and management of gas producers. Comparative values of the performances of the various types of producers, or of any particular type operated under varied conditions are valuable to all power consumers. The producer manufacturer is equally as well interested because such data gives him an opportunity to study his producer with the view of improving it and enables him to correctly represent his product to prospective purchasers.

In order that relative values of performances may be established, the adoption of some standard method of testing producers is essential. Various methods have been followed in testing but all are more or less incomplete. A complete rational method which has not as yet been given general publication has been developed by Mr. C. M. Garland, of the University of Illinois, in collaboration with A. P. Kratz, a graduate student of the University of Illinois.

In accordance with this latter method a series of tests was made upon a small producer in the Mechanical Engineering Laboratory of the University of Illinois. Their

object was to determine the efficiency of the producer under various loads. Four of the series are developed and discussed in the following pages. A more elaborate treatment of them is continued in a thesis by Mr. A. P. Kratz.

Description of the Producer.

The producer upon which the tests were made was of the suction type for the use of anthracite coal. It was built by the Otto Gas Engine Company, Philadelphia, Penn., and has a rating of 60 H. P. The general appearance and arrangement of the plant is clearly shown by the accompanying diagram on page 35, from which it is seen that the principal parts are the generator and economizer, the scrubber, the condenser, and the dryer. In this type the generator and economizer are integral, the latter being in the form of a water jacket surrounding the incandescent fuel bed. The generator is equipped with a small hand blower for furnishing air blast to start the producer. The wet scrubber, shown to the right of the generator, is cylindrical in form and filled with coke. Water decends over the coke and collects in the bottom to form a seal, the excess overflowing. To the right of the scrubber is a jet condenser into which a Schutle-Koeting steam ejector of 12000 cubic feet capacity per hour discharges the gas and steam drawn from the scrubber. The dryer consists of two telescopeing sheet iron cylinders within which is a large quantity of straw. Water forms an effective seal preventing the escape of gas between the two cylinders. A pipe

leads from the upper end of the inner cylinder to the two Westinghouse gas meters, one of 8000 cubic feet capacity and the other of 3500 cubic feet connected in paralell. From the meters the gas pipes discharge into the open air.

Method of Conducting the Test.

The purpose of the test determines the method of procedure. Since the object of the series of tests is to determine the efficiency of the producer under various loads, the general method requires that the energy imput and output together with the behavior of auxilliary apparatus be observed. Only such auxilliary observations are essential as tend to show the most economical way of operating the plant.

ARRANGEMENT OF APPARATUS.

Manometers consisting of U tubes containing water were placed at the suction orifice of the generator, at the ash pit, and at the exit of the gas from the producer. Thermometers were placed so as to determine the temperature of the water entering and leaving the scrubber and vaporizer, of the gas leaving the producer and scrubber and on entering the meter. Samples of gas were collected from the same orifice for chemical analysis and for heat determinations with the Junker's calorimeter.

OPERATION OF PLANT.

The charge of anthracite coal in the hopper gradually decends into the combustion zone over the grate where an

incandescent bed of fuel about two feet in depth is maintained. The intense heat of the fire is kept from affecting the cast iron shell of the generator by a lining of fire brick. Above the combustion zone surrounding the magazine is the vaporizer in which water is evaporated. The air passing from the entrance orifice travels over the water in the vaporizer and carries a load of vapor with it as it is drawn under the grate and up through the incandescent coal. Through the action of the heat upon the water, air, and coal, chemical action takes place, resulting in the formation of gas. The gas passes from the generator into the scrubber where it ascends thru the porous coke over which water is steadily falling. The porous nature of the coke allows a very intimate mingling of the gas and water that is very effective in the process of purification. Thus the gas is cleansed of impurities such as soot and tar. It is then drawn from the scrubber by a steam ejector and discharged into a jet condenser from which it passes through a dryer and thence through the meters and out through the open air. The steam ejector is used to secure the necessary draft because of the simplicity, convenience and absolute control of the suction which it gives, and which were deemed necessary to expedite the con duction of the test. Under commercial operating conditions the draft for starting is produced by a hand fan blower until the gas becomes of such a quality as to run the engine, the engine then furnishing the draft through the action of the piston.

UNIFORMITY OF CONDITIONS.

In order to insure a uniform quality of gas the conditions of operation must remain nearly constant throughout the test. The condition of the pressures of the steam and air blast, of the thickness of the fire and bed of ashes, the regularity of firing and quantity of coal fired at each time, frequency of poking, and intervals between times of cleaning fires all were kept as nearly uniform as possible.

STARTING AND STOPPING TEST.

The producer was fired and run for a time sufficient to bring all conditions up to a normal state. Then the tests proper were begun with a clean grate, full coal magazine, and the gas of a fair quality. The condition of the producer in all respects was nearly as possible the same at the close of the test as at the beginning. The fire was of the same quality, the ashes cleaned out and the hopper filled with coal.

FUEL AND ASH.

The coal was weighed and a representative sample of every shovel full taken as fired. Samples were taken as the magazine was charged at the start and at all other times except at the finish when the magazine was filled to leave in the state in which it was when the test began. All ashes were weighed and a representative sample for analysis taken by the following method which applies equally as well to the final selection of

the coal taken from the charging sample. Immediately after the test was over, the ash was broken, spread, mixed, and quartered by drawing two diagonals of a square, and the two opposite quarters were rejected. This was continued until a sample of two or three pounds remained which was preserved in well closed bottles for analysis.

GAS SAMPLING APPARATUS.

The method of securing representative gas samples is a matter seldom receiving due attention. The device used in these tests consists of three small tubes leading from a small chamber into the gas line. One pipe terminates just within the gas line, one at the center of the line and the other within a very short distance of the opposite wall, so that a representative quality of gas collects in the little chamber from which samples for the calorimeter and for chemical analysis are with-drawn. Continuous samples are with drawn for the latter purpose which insures an accurate representation of the gas produced.

ANALYSIS AND CALORIFIC VALUE OF GAS.

Hempel's method of volumetric determination was used for analysis from which the heating value was determined. A second determination of the heating value by Junker's calorimeter was used as a check.

JACKET WATER.

The water in the economizer was kept at nearly a

constant height by adjusting the supply so as to maintain a slight overflow and the net weight of the water was determined by weighing both supply and overflow. From the weight of the water evaporated the humidity of the air drawn thru the vaporizer and the moisture contained in the coal, the percentage of moisture supplied to the fire.was calculated.

SCRUBBER WATER.

The scrubber water was measured by a meter placed in the supply pipe. The meter read in cubic meters.

MOISTURE DETERMINATIONS.

A continuous sample of gas is with drawn from the generator discharge pipe by means of a small aspirator and passed thru a small cooler, on thru a meter, and then thru a vessel containing Calcium chloride. In its passage the gas gives up its moisture to the chloride. Then from the increase weight of the chloride due to the moisture obtained from the gas, and the volume of gas as indicated by the small meter, the total moisture of the gas may be calculated.

HIGH TEMPERATURE DETERMINATIONS.

The high temperatures of the gas as it left the generator and of the fuel bed in the various zones were determined by means of a thermo-couple. A platin um- rhodium-couple protected by porcelain tube was used in connection with a galvanometer reading directly in degrees Centigrade.

THEORY OF GAS PRODUCTION.

Producer gas is the product of incomplete combustion of fuel in a generator or producer. In a measure the action which takes place depends upon the type of producer and upon the kind of fuel. In the suction type of producer using anthracite coal which contains a large percentage of carbon and but little volitile matter, the action is as follows:- Water vapor and air pass thru the ash zone and enter the combustion zone of the generator. Here the incandescent carbon unites with the oxygen to form $C\ O_2$, while the water vapor becomes superheated steam and possibly begins to decompose. In the upper strata of the combustion zone the $C\ O_2$ takes up more C and becomes C O, while the steam is decomposed into H and O . These reactions require high temperatures, not lower than 1800° F. The fuel just above the fire is heated so that volatile matter is driven off and the hydro carbons resulting add to the heating value of the gas when driven off at sufficiently high temperatures.

Steam or water vapor is introduced in order that the calorific power of the gas may be increased by the presence of the hydrogen and to eliminate the formation of clinker in the fuel bed. Its effect is to absorb the heat on the grate and to carry it to the incandescent fuel bed. Also by moistening the ashes and keeping them soft and porous it allows a uniform passage of air thru the fire.

However, an excessive use of steam results in part of it passing thru the fire without being decomposed and then appearing in the form of water vapor in the gas thus decreasing the fuel value of the gas.

General Discussion.

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An examination of the average results and of the log sheets shows that the generally accepted theories of producer operation readily account for the behavior of the various parts of the producer during the tests. Some of these general theories are as follows:

(1.) The effect of allowing too much moisture in the air as it passes thru the fuel bed is to cause an excess of $C\ O_2$ in the gas.

(2) Careful operation is necessary in charging and in cleaning the grates in order that the quality of the gas may not be impaired. Air admitted thru the charging hopper and thru leaks so that it does not pass thru the fire causes a very lean gas to be formed.

(3) The temperature of the gas varies with the rate of gasification.

CONCLUSION.

A general conclusion is that the producer does not come up to its rated capacity. The maximum efficiency was obtained with the largest load. Other than these general statements are not warranted because of the small number of the tests.

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CALCULATIONS :-

The following will show the method of arriving at some of the results obtained; the others being self evident.

Item 16.- The depth of fuel bed was taken as the distance between the upper edge of the ash zone and the section where the gases separate from and leave the fuel.

Item 43.- The weight of dry coal equals the total weight of coal as fired minus the weight due to moisture in the coal or

$$\text{Item 43.} = \text{Item 41.}\left(1 - \frac{\text{Item 48.}}{100}\right)$$

Item 46.- The total weight of combustible consumed is taken as the total weight of dry coal fired minus weight of ash, computed from the analysis minus the weight of nitrogen minus 1 1/8 times the weight of oxygen minus the weight of carbon contained in ash and refuse.

$$\text{Then Item 46.} = \text{Item 43.} - \frac{\text{Item 43. x Item 58.}}{100} - \frac{\text{Item 43. x Item 56.}}{100} - \frac{1\ 1/8 \text{ x Item 43. x Item 55.}}{100} - \frac{\text{Item 44. x Item 60.}}{100}.$$

$$\text{Item 47.} = \frac{\text{Item 44.}}{\text{Item 43.}} \text{ x } 100.$$

$$\text{Item 62.} = \frac{\text{Item 43.}}{\text{Hours}}$$

$$\text{Item 63.} = \frac{\text{Item 46.}}{\text{Hours.}}$$

Item.64. $= \frac{\text{Item 62.}}{\text{Item 14.}}$

Item 65. $= \frac{\text{Item 63.}}{\text{Item 14.}}$

Item 66. $= \frac{\text{Item 62.}}{\text{Item 17.}}$

Item 67. $= \frac{\text{Item 63.}}{\text{Item 17.}}$

Item 68. $= \frac{\text{Item 66.}}{\text{Item 16.}}$

Item 69. $= \frac{\text{Item 67.}}{\text{Item 16.}}$

Item 71. $= \frac{\text{Item 70. x Item 43.}}{\text{Item 46.}}$

Item 72.- The heating value by analysis is given by the formula : $14540\ C + 4000\ S + 62000(\ H - \frac{O}{8}\ )$. Where C, S, H, and O represent the percentages of carbon, sulphur, hydrogen and oxygen respectively contained in the fuel. The constants represents the heating values of the products.

Then Item 72. $= \frac{1}{100}\Big(\text{Item 53. x 14540} + \text{Item 57. x 4000} +$ $(\text{Item 54.} - 1/8 \text{ x Item 55.})\ 62000.\Big)$

Item 73. $= \frac{\text{Item 72 x Item 43.}}{\text{Item 46.}}$

Item 76. = Item 74. - Item 75.

Item 77. = Item 76. + Item 77_b + Item 77_c.

Item 77_b - The weight of water fed to the producer in the air equals the percent of moisture in the air times the total weight of dry air used times 1/100 or

$$\text{Item } 77_b = \frac{\text{Item 95 x Item 96.}}{100}$$

$$\underline{\text{Item } 77_c} = \frac{\text{Item 41. x Item 42.}}{100}$$

$$\underline{\text{Item 78.}} = \text{Item 77. - Item 79.}$$

$$\underline{\text{Item 79.}} = \frac{\text{Item 100 x Item 111.}}{100}$$

$$\underline{\text{Item 80.}} = \text{Item 77. - Item 78. - } \frac{\text{Item 100 x Item 111}}{100}$$

$$\underline{\text{Item 81.}} = \frac{\text{Item 80.}}{\text{Item 77.}} \text{ x 100.}$$

$$\underline{\text{Item 82.}} = \frac{\text{Item 78.}}{\text{Item 77.}}$$

$$\underline{\text{Item 83.}} = \frac{\text{Item 78.}}{\text{Item 111.}}$$

$$\underline{\text{Item 84.}} = \frac{\text{Item 78.}}{\text{Item 48.}}$$

$$\underline{\text{Item 85.}} = \frac{\text{Item 78.}}{\text{Item 46.}}$$

$$\underline{\text{Item 86.}} = \frac{\text{Item 78}}{\text{Item 96.}}$$

$$\underline{\text{Item 87.}} = \frac{\text{Item 77.}}{\text{Item 43.}}$$

$$\underline{\text{Item 88.}} = \frac{\text{Item 77.}}{\text{Item 46.}}$$

$$\underline{\text{Item 89.}} = \frac{\text{Item 77.}}{\text{Item 96.}}$$

$$\underline{\text{Item 91.}} = \frac{\text{Item 76.}}{\text{Hours.}}$$

$$\underline{\text{Item 92.}} = \frac{\text{Item 91.}}{\text{Item 22.}}$$

$$\underline{\text{Item 93.}} = \frac{\text{Item 77.}}{\text{Hours.}}$$

<u>Item 94</u>. = $\frac{\text{Item 90.}}{\text{Hours.}}$

<u>Item 95</u>. - The percent moisture in air, percent by weight of dry air is given by the formula $\frac{Pn}{100m} \times 100 = \frac{Pn}{m}$ where P = percent saturation or the relative humidity of the air, n = weight of moisture contained in one cubic foot of saturated air at the temperature of the fire room or Item 31., m = weight of one cubic foot of dry air at the observed temperature, $\frac{Pn}{100}$ = weight of moisture in one cubic foot of air as used. Then Item 95. = $\frac{Pn}{m}$. (See Kent p. 484 for weight of air and moisture.)

<u>Item 96</u>. - The total weight of air used was calculated from the weight of nitrogen appearing in the gas. This nitrogen comes from the air used and from the nitrogen introduced with the fuel. Taking analysis by weight of N_2 pounds.

The total weight of N_2 in the gas = $\frac{W\ N_2}{100}$ where W is the total weight of the gas.

The weight of N_2 supplied by the fuel = $\frac{W_1\ H_1}{100}$ where W_1 = weight of dry coal and H_1 = percent by weight of N_2 contained in the fuel.

The total weight W_4 of N_2 in the air is therefore:-

$$W_4 = \frac{W\ N_2}{100} - \frac{W_1\ H_1}{100}$$

Then the total weight of air supplied = $\frac{W_4}{.77} = \frac{W\ N_2 - W_1 H_1}{.77}$

$$\text{or Item 96.} = \left[(\text{Item 111.} \times \frac{.074 \times \text{Item 123.}}{\text{Item 104.}}) - (\text{Item 43.} \times \text{Item 56.}) \right] \frac{1}{77}.$$

$$\underline{\text{Item 97.}} = \frac{\text{Item 96.}}{\text{Hours.}}$$

$$\underline{\text{Item 98.}} = \frac{\text{Item 96.}}{\text{Item 43.}}$$

$$\underline{\text{Item 99.}} = \frac{\text{Item 96.}}{\text{Item 46.}}$$

$$\underline{\text{Item 100.}} = \frac{\text{Item 77. - Item 78.}}{\text{Item 14.}} \times 100.$$

<u>Item 104</u>. - The sum of the products of the constituents of the gas by volume times their respective specific weights at 62° F. and 30 inches Hg. x 1/100 gives the specific weight of the standard gas in pounds per cubic foot.

Then Item 104. =(Item 115. x .1161 + Item 116. x .07262 + Item 117. x .08418 + Item 118. x .00530 + Item 119. x .04278 + Item 120. x .0737 + Item 121. x .1638 + Item 122. x .08682 + Item 123. x .0740) $\frac{1}{100}$.

<u>Item 105</u>. - Taking the specific heat of the gases for constant pressure.

For CO_2, $C_p = .19 - .0000977\ t$,----(a).

" H_2O, $C_p = .426 - .000176\ t$,----(b).

" H_2 , $C_p = 3.355 - .000678t$,----(c).

" CO , $C_p = .24 - .0000484\ t$,----(d).

" N_2 , $C_p = .24 - .0000484\ t$,----(e).

" CH_4 , $C_p = .6$-------------------(f).

" O_2 , $C_p = .21 - .0000424\ t$,----(g).

t = temperature of gas leaving producer outlet or

Item 37. The specific heat of the producer gas is equal to the sum of the products of the constituents of the gas by weight times the specific heat of the constituent.

$$\text{Then Item 105.} = \Big[\left(a \times \frac{.1161 \times \text{Item 115.}}{\text{Item 104.}}\right) + \left(c \times \frac{.00530 \times \text{Item 118.}}{\text{Item 104.}}\right) + \left(d \times \frac{.07262 \times \text{Item 116.}}{\text{Item 104.}}\right) + \left(e \times \frac{.0740 \times \text{Item 123.}}{\text{Item 104.}}\right) + \left(f \times \frac{.04278 \times \text{Item 119.}}{\text{Item 104.}}\right) + \left(g \times \frac{.08418 \times \text{Item 117.}}{\text{Item 104.}}\right)\Big] \frac{1}{100}.$$

Item 106.- The total weight of carbon appearing in a unit weight of gas = (% by weight CO_2 x $\frac{3}{1100}$ + % by weight CO x 3/700 + % by weight CH_4 x 3/400 + % by weight C_2H_4 x $\frac{6}{700}$).

The total weight of H_2 appearing in a unit weight of gas = 1/100 % by weight H_2 + % by weight CH_4 x 1/4 + % by weight C_2H_4 x 1/7 or Item 106. =

$$\frac{\left[\%\,CO_2 \times \frac{3}{11} + \%\,CO \times \frac{3}{7} + \%\,CH_4 \times \frac{3}{4} + \%\,C_2H_4 \times \frac{6}{7}\right]}{\left[\%\,H_2 + \%\,CH_4 \times \frac{1}{4} + \%\,C_2H_4 \times \frac{1}{7}\right]}, \text{ where}$$

analysis is given % by weight.

Item 107.- The volume is calculated from the analysis of the gas and the analysis of the coal.

The total weight of the carbon appearing in the gas should equal the total weight of carbon in the coal minus the weight that is lost thru the grate minus the weight lost in

soot and tar. The latter being very small was neglected.

The weight of the carbon consumed in the producer = W_2 = $\frac{PW - P_1W_1}{100}$, where P and P_1 represent the % by weight of carbon in dry coal and ash respectively; and W and W_1 = total weight of dry coal and ash respectively. The carbon is contained in the CO_2, CO, CH_4, and C_2H_4. The total weight of carbon contained in a unit weight of gas = W_3 = (3/11 CO_2 + 3/4 CO - 6/7 C_2H_4) x 1/100, where CO_2, CH_4, CO, and C_2H_4 represent % by weight from gas analysis. The % of carbon contained in gas as $CO_2 = \frac{\text{\% by weight } CO_2 \times 3/11}{W_3}$. The actual weight of this carbon = $\frac{\text{\% by weight } CO_2 \times 3/11}{W_3 \times 100} \times W_2$. Total weight of CO_2 in gas = $W_2 + \frac{\text{\% by weight } CO_2 \times 3/11}{W_3 \times 100} \times 3\ 2/3$. The standard volume of $CO_2 = \frac{\text{\% by weight } CO_2 \times W_2}{W_3 \times 100 \times W_s}$, where W_s = specific weight of CO_2 at 62° F. and 30 in. Hg.

This volume is (a) % of the total volume of gas delivered by the producer. Then the total volume of standard gas from the gas analysis = $\frac{\text{\% by weight } CO_2 \times W_2}{W_3 \times W_s \times a}$ or Item 107. =

$$\frac{\left(\frac{.1161 \times \text{Item 115.}}{\text{Item 104.}}\right) \times (\text{Item 43.} \times \text{Item 53.} - \text{Item 44.} \times \text{Item 60.})}{.1161 \times \text{Item 115.}\left(\frac{3}{11} \times \%\ CO_2 + \frac{3}{4} \times \%\ CH_4 + \frac{3}{7} \times \%\ CO + \frac{6}{7} \times \%\ C_2H_4\right)}$$

where analysis if gas is used as % by weight.

$$\underline{\text{Item 108}}. = \frac{\text{Item 107.}}{\text{Hours.}}$$

Item 109. $= \frac{\text{Item 107.}}{\text{Item 43.}}$

Item 110. $= \frac{\text{Item 107.}}{\text{Item 46.}}$

Item 111. = Item 107. x Item 104.

Item 112. $= \frac{\text{Item 111.}}{\text{Hours.}}$

Item 113. $= \frac{\text{Item 111.}}{\text{Item 43.}}$

Item 114. $= \frac{\text{Item 111.}}{\text{Item 46.}}$

Item 124. The grate efficiency is the ratio of the total B. T. U. contained in the fuel minus the B. T. U. in the fuel lost thru thr grate, to the total B. T. U. contained in the fuel, times 100; or Item 124. =

$$\frac{\text{Item 43. x Item 70. x 100 - Item 44. x Item 60. x 14540.}}{\text{Item 43. x Item 70.}}$$

Item 125. The hot gas efficiency is the ratio of the total heat of combustion of the gas plus the sensible heat of the gas, to the total heat of combustion of the fuel plus the sensible heat of the fuel and the sensible heat contained in the air and moisture times 100. The sensible heat of the fuel, air and moisture is ordinarily very small and these quantities are neglected.

Then Item 125. = [Item 102. x Item 107 + Item 105. x Item 111. x Item 37. - 62° + Item 79. x 1116 + .6(Item 37. - 212°)] x 100. ÷ Item 49. x Item 74.

The specific heat of superheated steam is taken at .6

Item 126. The cold gas efficiency is the ratio of the total heat of combustion of the gases to the total heat of combustion of the fuel times 100. or Item 126. =

$$\frac{\text{Item 102 x Item 107.}}{\text{Item 43. x Item 70.}} \times 100.$$

$$\text{Item 128.} = \frac{\text{Item 127. x Item 41.}}{\text{Item 107. x 2000.}}$$

$$\text{Item 129.} = \frac{\text{Item 90. x 1000.}}{\text{Item 107. x 62.5}}$$

Heat Balance -A-

Debit:-

1. The total heat supplied per pound of dry coal is taken as the calorific value by oxygen calorimeter or Item 70.

2. Item 98. x .24(Item 31. - 62°F.)

3. $\frac{\text{Item } 77_b \text{ x (H - 1070)}}{\text{Item 43.}}$ where H = total heat in one pound of saturated steam at temperature of the fire room.

4. $\frac{\text{Item 43. x Item 2.}}{\text{Item 43 x 100}}$ (Item 31. - 62°F.)

5. .24 x (Item 31. - 62°F.)

6. $\frac{\text{Item 77a (Item 33. - } 62^\circ\text{F.)}}{\text{Item 43.}}$

Credit:-

1. Item 105. x Item 113. x (Item 37. - 62°F.)

2. $\frac{\text{(Item 100 x Item 113)x[(Item 37. - } 212^\circ\text{F.)x 1116x .6]}}{100.}$

3. Item 102. x Item 109.

4. $\frac{\text{Item 44. x Item 60.}}{\text{Item 43. x 100}} \times 14540.$

5. This is very small and is neglected.

6. $\frac{\text{Item 75.}}{\text{Item 43.}}$ x (Item 34. - Item 33.)

7. The radiation and condition is equal to the sum of the items on the debit side minus the sum of the items 1, 2, 3, 4, 5, and 6 of the credit side.

Heat Balance -B-

Debits:-

1. % CO_2 by weight x Item 113. x 3980.

2. % CO by weight x Item 113. x 1850.

3. Item 57. x 40.

4. This is the total heat from the items 2, 3, 4, 5, and 6 of the Heat Balance A.

Credits:-

1. Same as item 1. of A.

2. Same as item 2. of A.

3. $\frac{\text{Item 78. x 6890.}}{\text{Item 43.}}$

4. The heat contained in the ash and refuse as sensible heat is small and is neglected.

5. Same as item 6. of A.

6. Sum of items on debit side minus sum of items 1, 2, 3, 4, and 5 of the credit side.

R E S U L T S.

O F

GAS PRODUCER TRIALS.

1.	Test number -	6	7	8	9
2.	Made by --- Kratz, Evans, Kerr, McGinnis & Johanning				
3.	At - - - Mechanical Engineering Laboratory University of Illinois				
4.	Kind of Producer - - - Otto.				
5.	To determine - - - Thermal Efficiency.				
6.	Principal conditions governing trial.				
7.	Kind of fuel - - - Philadelphia & Reading Coal.				
8.	Kind of grate - - - Plain bar grate.				
9.	Method of starting and stopping test.				
10.	Type of producer - - - Suction.				
11.	Form of blower - - - Ejector.				
12.	Date of trial -	Dec 29,08	Dec 30,08	Jan 1,09	Jan 2,09
13.	Duration of trial - - - - - - - - - - - - - - - - - -	8 hrs.	9 hrs.	9 hrs.	9 hrs.
	Dimensions and Proportions.				
14.	Grate area, square feet - - - - - - - - - - - - - -	1.666	---	---	---
15.	Dimensions of grate, inches - - - - - - - - - - - -	15" x 16"	---	---	---
16.	Depth of fuel bed, ft. - - - - - - - - - - - - - -	2.21	---	---	---
17.	Area of fuel bed- - - - - - - - - - - - - - - - - -	1.767	---	---	---
18.	Height of discharge pipe above grate, ft. - - - - -	2.875	---	---	---
19.	Approximate width of air spaces in grate, inches- -	.5	---	---	---

20.	Proportion of air space to whole grate area % - -	43.33	---	---	---
21.	Area of discharge pipe, sq. ft. - - - - - - - - - - -	.165	---	---	---
22.	Water heating surface in vaporizer, sq. ft. - - - -	2.074	---	---	---
23.	Outside diameter of shell, ft. - - - - - - - - - - -	2.833	---	---	---
24.	Length of shell from base to top of magazine, ft. -	7.125	---	---	---
25.	Ratio of water heating surface to grate area,-to 1	1.25	---	---	---
26.	Ratio of minimum draft area to grate area, 1 to - -	2.32	---	---	---
	Average pressures.				
27.	Draft in ash pit, ins. water - - - - - - - - - - - -	1.03	.64	2.20	.616
28.	Suction at producer outlet, ins. water - - - - - - -	.81	1.64	6.95	1.64
29.	Pressure at meters, ins. water- - - - - - - - - - - -	5.20	1.51	5.59	1.61
30.	Corrected barometer reading, ins. mercury - - - - -	29.339	29.312	29.593	29.460
	Average Temperatures.				
31.	Of fire room, degrees F - - - - - - - - - - - - - - -	63.7	66.8	70.1	70.3
32.	Of steam, leaving vaporizer, degrees, F - - - - - - -	212.	212.	212.	212.
33.	Of feed water entering vaporizer, degrees, F - - -	59.3	61.4	59.9	60.9
34.	Of overflow from vaporizer, degrees, F - - - - - - -	200.7	189.5	204.3	192.9
35.	Of water entering scrubber, degrees, F - - - - - - -	57.	56.8	55.5	56.6
36.	Of water leaving scrubber, degrees F - - - - - - - -	157.	99.4	131.6	96.8
37.	Of gases leaving producer, degrees F - - - - - - - -	1213.	833.5	1104.	991.1

38.	Of gases leaving scrubber, degrees F	92.7	70.12	78.8	68.1
39.	Of gases entering meter, degrees F	122.7	73.1	90.7	76.7
	F u e l.				
40.	Size and condition ---- Chesnut				
41.	Weight of coal as fired, Lb.	950	382	669	318
42.	Percentage of moisture in coal	1.97	2.40	2.40	2.10
43.	Total weight of dry coal fired, lb.	932	327.8	653	311
44.	Total ash and refuse, lb.	325	91.5	177	69
45.	Quality of ash and refuse	Contained clinker & partially burned coal.			
46.	Total combustible consumed, lb.	579.2	257.5	437.8	217.76
47.	Percentage of ash and refuse in dry coal	34.9	24.54	27.15	22.2
	Proximate analysis of coal.				
48.	Fixed carbon	79.01	79.11	78.93	79.82
49.	Volatile matter	6.23	5.58	6.12	4.95
50.	Moisture	1.97	2.40	2.40	2.10
51.	Ash	12.79	12.91	12.55	13.13
52.	Sulphur, separately determined	1.28	0.78	0.83	0.80
	Ultimate analysis of dry coal.				
53.	Carbon (C)	81.30	80.98	81.30	80.77
54.	Hydrogen (H_2)	1.90	2.30	2.30	2.30

55.	Oxygen (O_2) -	1.68	1.88	1.87	1.88
56.	Nitrogen (N_2) - - - - - - - - - - - - - - - - - -	0.82	.82	.82	.82
57.	Sulphur (S) -	1.28	0.80	.85	.82
58.	Ash -	13.00	13.23	12.86	13.41
59.	Moisture in sample of coal as received - - - - - -	1.97	2.40	2.40	2.10
	<u>Analysis of dry ash and refuse.</u>				
60.	Carbon per cent - - - - - - - - - - - - - - - - - -	63.49	60.16	63.37	61.47
61.	Earthy matter, per cent - - - - - - - - - - - - - -	36.51	39.84	36.63	38.53
	1. SiO_2- - - - - - - - - - - - - - - - - - - -				
	2. AlO_3- - - - - - - - - - - - - - - - - - - -				
	3. MnO_2- - - - - - - - - - - - - - - - - - - -				
	4. Fe -				
	<u>Fuel per hour.</u>				
62.	Dry coal fired per hour, lb. - - - - - - - - - - - -	116.5	41.4	72.6	34.55
63.	Combustible consumed per hour, lb. - - - - - - - - -	72.45	28.6	48.64	24.2
64.	Dry coal per sq. ft. of grate area per hour, lb.- -	69.8	24.86	43.6	20.73
65.	Combustible per sq.ft. of grate area per hr., lb. -	43.5	17.2	29.2	14.52
66.	Dry coal per sq. ft. of fuel bed per hour, lb. - -	65.9	23.4	41.1	19.55
67.	Combustible per sq.ft. of fuel bed per hr., lb. - -	41.0	16.16	27.55	13.70
68.	Rate of decent of dry coal thru fuel bed, lb. per ft. per hour. - - - - - - - - - - - - - - - - - -	29.8	10.58	18.6	8.85

69.	Rate of decent of combustible thru fuel bed , lb. per ft. per hour.	18.55	7.32	12.46	6.2
	<u>Calorific value of fuel.</u>				
70.	Calorific value by oxygen calorimeter per lb. dry coal B.t.u.	12860	12887	12872	12940
71.	Calorific value by oxygen calorimeter per lb. of combustible B.t.u.	20700	18650	19210	18490
72.	Calorific value by analysis, per lb. dry coal B.t.u.	12925	13072	13130	13060
73.	Calorific value by analysis per lb. of combustible B.t.u.	20800	18920	19580	18650
	<u>W a t e r.</u>				
74.	Total weight of water fed to vaporizer, lb.	1034.8	536.5	1253.	643
75.	Total weight of overflow from vaporizer, lb.	354	202.5	631	252.25
76.	Water actually evaporated in vaporizer, lb.	680.8	334	622	290.75
77.	Total weight of water fed to producer, lb.	745.1	362.8	676	316.2
	a From vaporizer	680.8	334	622	290.75
	b In air	45.6	19.64	37.9	18.77
	c In coal	18.72	9.20	16.1	6.68
78.	Total weight of water decomposed,	135	60.6	72.23	41.15
79.	Total wt. of water in gas leaving producer, lb.	610	302.2	603.77	275.1
80.	Total weight of water unaccounted for, lb.	120	4.2	51.97	80.7
81.	Per cent of water supplied to producer unaccounted for per cent	16.1	1.16	7.7	25.5

82.	Ratio of water decomposed to water supplied - - - -	.181	.167	.107	.130
83.	Ratio of water decomposed to gas generated, lb. water per lb. gas. - - - - - - - - - - - - - - - - - -	.0247	.0293	.0195	.0235
84.	Ratio of water decomposed to dry coal fired.- - - -	.144	.163	.1106	.132
85.	Ratio of water decomposed to combustible consumed -	.233	.236	.165	.189
86.	Ratio of water decomposed to air supplied - - - -	.0281	.0349	.0227	.0278
87.	Ratio of water supplied to dry caal fired - - - - -	.80	.97	1.035	1.02
88.	Ratio of water supplied to combustible consumed - -	1.29	1.41	1.545	1.45
89.	Ratio of water supplied to air used.- - - - - - - -	.155	.219	.212	.214
90.	Total weight of scrubber water. - - - - - - - - - -	19.948	18.850	22056	17037
	Water per hour.				
91.	Water evaporated per hour in vaporizer, lb. - - - -	85.1	37.1	69.1	32.3
92.	Water evaporated per hour, per sq. ft. of water heating surface in vaporizer, lb. - - - - - - - - - -	41.0	17.9	33.32	15.57
93.	Total weight of water fed to producer per hour, lb.	93.2	40.3	75.1	35.13
94.	Weight of scrubber water used per hour, lb. - - - -	2493	2094	2450	1893
	Quantity of Air.				
95.	Per cent of moisture in air, °/o of dry air - - - -	.948	1.13	1.19	1.23
96.	Total weight of dry air, lb. - - - - - - - - - - - -	4800	1738	3186	1478
97.	Total weight of dry air per hour - - - - - - - - - -	600	193.1	354	164
98.	Ratio of dry air used to dry coal fired, lb. air per lb. coal - - - - - - - - - - - - - - - - - - -	51.5	4.66	4.88	4.75

99.	Ratio of dry air used to combustible consumed, lb. air per lb. combustible	82.8	6.75	7.28	6.79
	Gas.				
100.	Per cent moisture in gas leaving producer, $^0/_0$ of dry gas	13.4	14.4	14.85	11.10
101.	Per cent of soot and tar in gas leaving producer	0	0	0	0
102.	Calorific value of standard gas from analysis (High Value) B. t. u. per cu. ft.	67.36	93.05	84.3	94.8
103.	Calorific value of standard gas from calorimeter (High Value) B. t. u.	96.8	89.56	95.06	98.5
104.	Specific weight of standard gas, Lb. per cu. ft.	.07327	.0713	.07235	.0713
105.	Specific heat of gas leaving producer	.3243	.3085	.3198	.3156
106.	Carbon ratio C/H	14.55	12.67	13.87	12.95
107.	Total volume Standard gas, cu. ft.	74400	29050	51350	24540
108.	Volume of Standard Gas per hour, cu. ft.	9300	3228	5705	2727
109.	Volume of Standard Gas per lb. of dry coal	79.8	77.9	78.6	78.9
110.	Volume of Standard Gas per lb. of combustible	128.5	112.8	117.3	115.7
111.	Total weight of Standard Gas, lb.	5450	2070	3715	1750
112.	Weight of standard gas per hour, lb.	681.3	230.	412.7	194.4
113.	Ratio of total weight of standard gas to total weight of dry coal	5.85	5.55	5.69	5.62
114.	Ratio of total weight of standard gas to total weight of combustible	9.42	8.02	8.49	8.05

	<u>Gas Analysis by volume.</u>				
115.	Carbon dioxide (CO_2) - - - - - - - - - - - - - - - - - -	12.32	10.98	11.06	10.33
116.	Carbon monoxide (CO) - - - - - - - - - - - - - - - - - -	10.56	14.73	13.60	15.14
117.	Oxygen (O_2) -	0.92	0.63	0.79	0.83
118.	Hydrogen (H_2) - - - - - - - - - - - - - - - - - - -	8.30	9.93	8.48	8.99
119.	Marsh gas (CH_4)- - - - - - - - - - - - - - - - - - -	.64	1.33	1.30	1.67
120.	Olefiant gas (C_2H_4)- - - - - - - - - - - - - - - - -	---	---	---	---
121.	Sulphur dioxide (SO_2) - - - - - - - - - - - - - - - -	---	---	---	---
122.	Hydrogen Sulphide (H_2S) - - - - - - - - - - - - - - -	---	---	---	---
123.	Nitrogen (H_2) by difference - - - - - - - - - - - - -	67.26	62.40	64.77	63.04
	<u>Efficiency.</u>				
124.	Grate efficiency - - - - - - - - - - - - - - - - - - -	75.0	83.4	80.7	84.6
125.	Hot gas efficiency, based on high heating value %	67.5	75.9	78.2	81.3
126.	Cold gas efficiency, based on high heating value % -	41.8	56.3	51.5	57.7
	<u>Cost of gasification.</u>				
127.	Cost of fuel per ton delivered in producer room - -	\$8.25	8.25	8.25	8.25
128.	Cost per cu. ft. of standard gas - - - - - - - - - -	.0526	.0541	.0538	.0534
129.	Cu. ft. scrubber water per 1000 cu. ft. gas - - -	4.28	16.37	6.87	11.1
	<u>P o k i n g.</u>				
130.	Method of poking - - - - - - - - - - - - - - - - - - -	From top and bottom.			

131. Frequency of poking - - - - - - - - - - - - - - - - -		3 hrs.	2 hrs.	3-1/2 hr.
Firing.				
132. Method of firing -		Hand		
133. Average intervals between firing - - - - - - - - - -		3	2-1/2	5
134. Average amount of fuel charged each time - - - - -		127	170	160
Heat Balance. --- A.				
DEBIT.				
1. Total heat supplied per lb. dry coal. - - - - - - - -	12860	12887	12870	12940
2. Total heat supplied by air per lb. dry coal - - - -	2.1	5.37	9.5	9.46
3. Total heat supplied by moisture in air per lb. dry coal -	1.54	1.7	1.93	2.02
4. Total heat supplied by moisture in coal per lb. dry coal -	.034	.12	.199	.178
5. Total heat supplied as sensible heat in coal per lb. dry coal -	.41	1.2	1.95	199
6. Total heat supplied by water in vaporizer per lb. dry coal -	-1.95	- .54	-2.0	-1.03
CREDIT				
1. Heat contained as sensible heat in dry gas - - - -	2185	1317	1895	1648
2. Heat contained in moisture - - - - - - - - - - - - - -	1125	1205	1528	1400
3. Heat contained in dry gas - - - - - - - - - - - - - - -	5377	7250	6625	7480
4. Heat in unburned carbon - - - - - - - - - - - - - - - -	3220	2146	2498	1984

5.	Heat contained in ash & refuse as sensible heat - -	Neglected			
6.	Heat lost in overflow from vaporizer - - - - - - - -	53.7	70	140	149.5
7.	Heat lost in radiation & conduction - - - - - - - - - -	89.9	90.8	196	291.

Heat Balance. --- B.

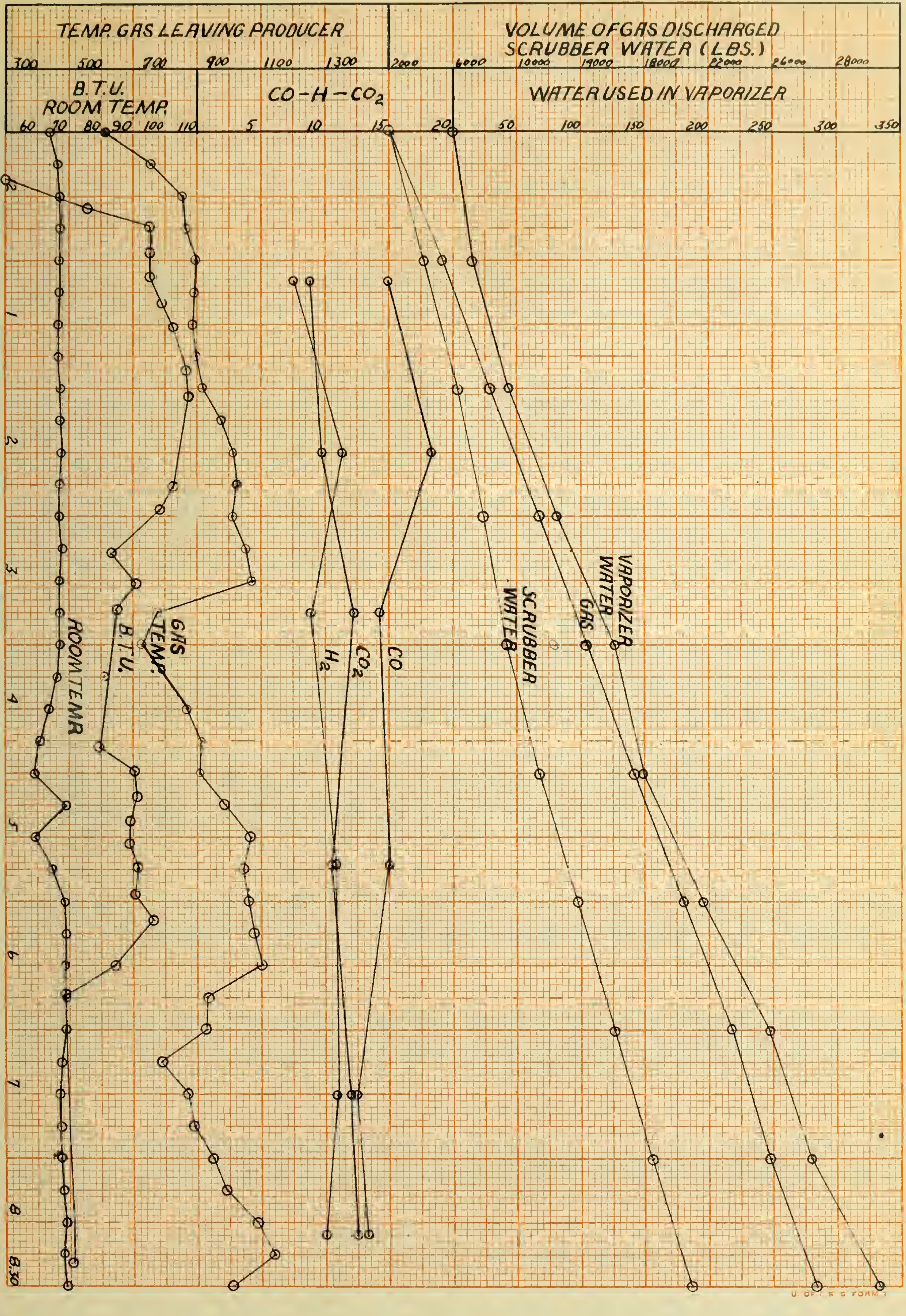
DEBIT.

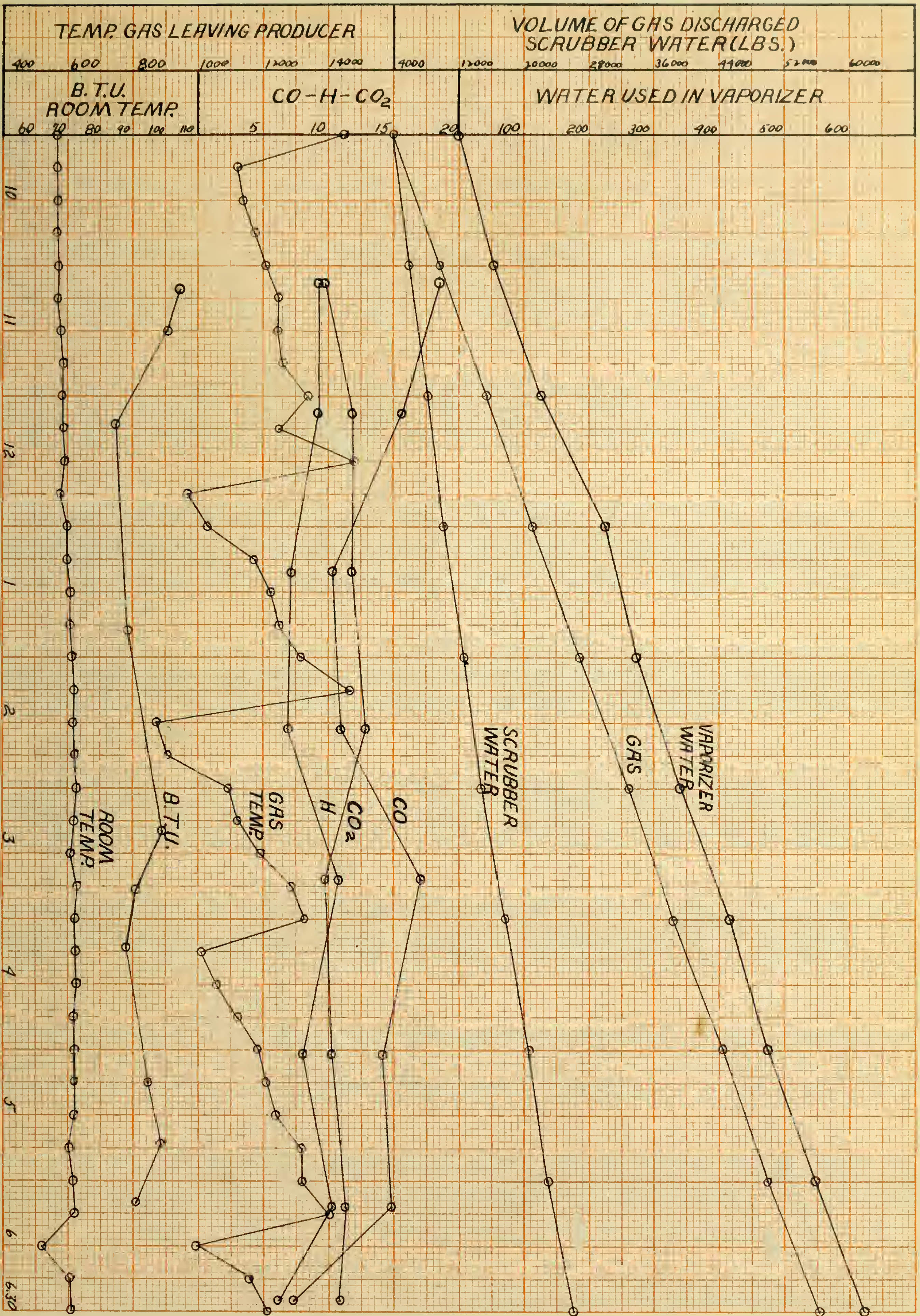
1.	Total heat equivalent of CO_2 formed per lb. dry coal	4548	3955	4022	3750
2.	Total heat equivalent of CO formed per lb. dry coal	1132	1540	1437	1600
3.	Total heat equivalent of SO formed per lb. dry coal	51.2	32	34	33
4.	Total heat from Items 2, 3, 4, 5, 6 of A. - - - - - -	2.0	9	12	13

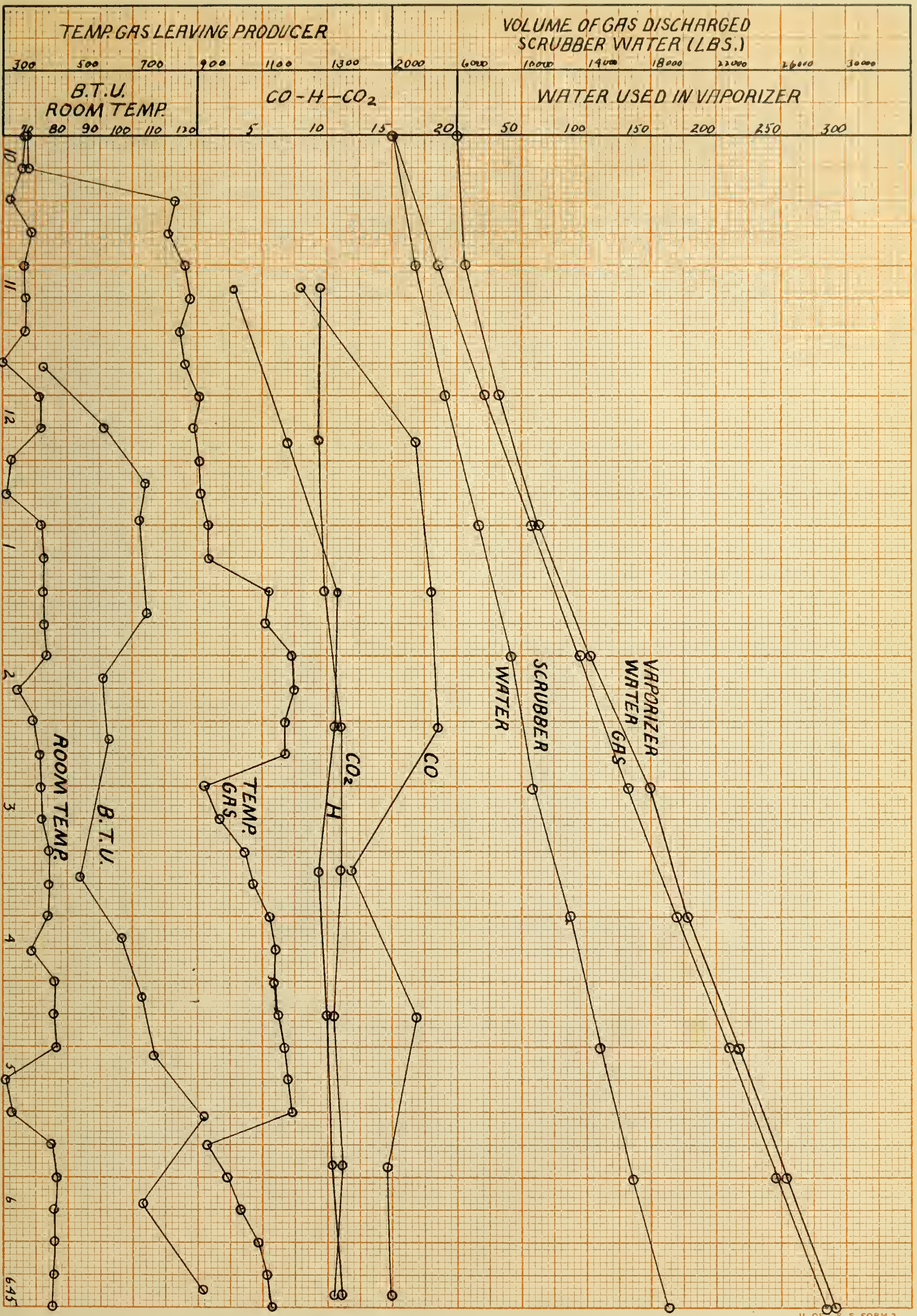
CREDIT.

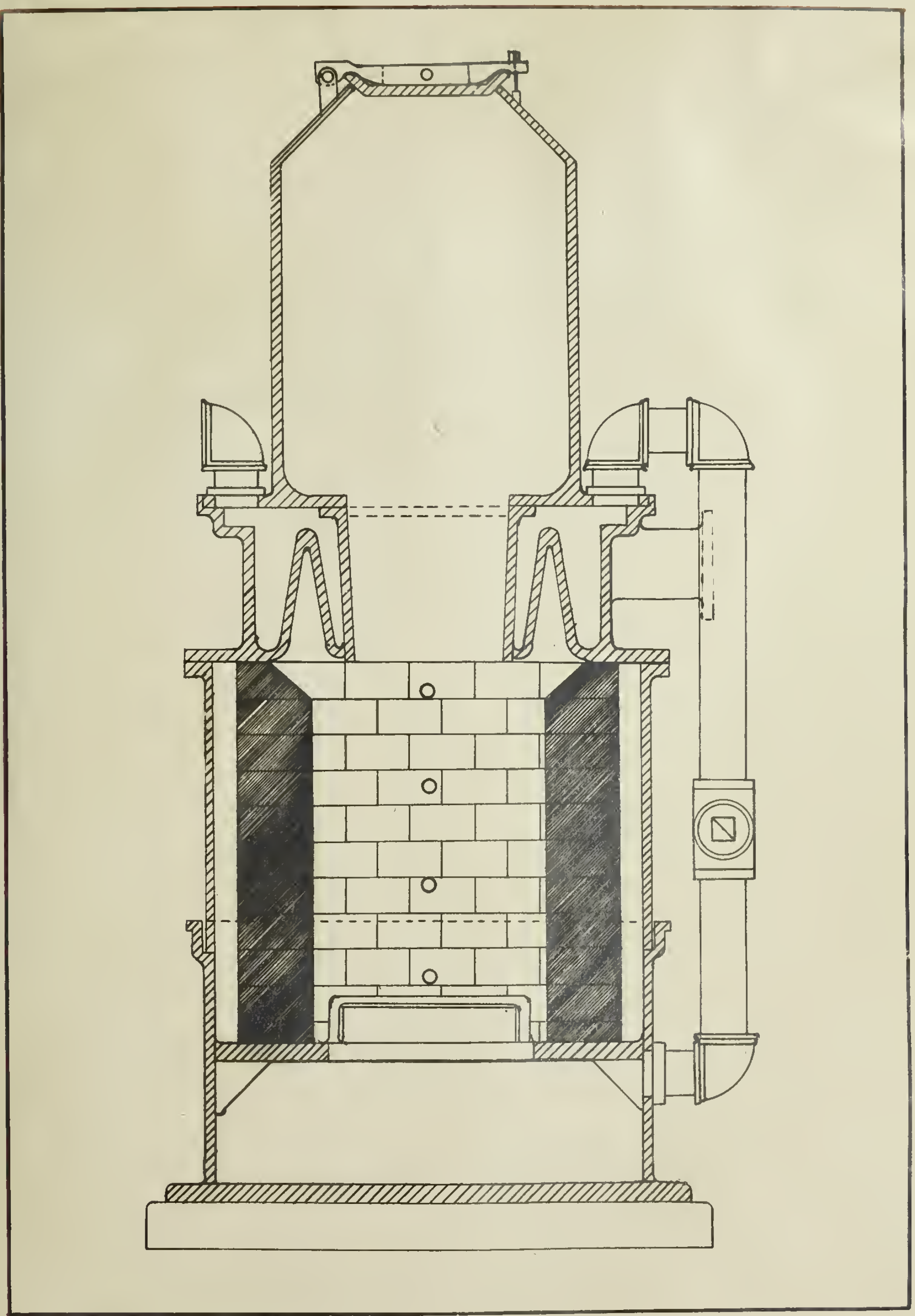
1.	Sensible heat in dry gas - - - - - - - - - - - - - -	2185	1317	1895	1648
2.	Heat in moisture - - - - - - - - - - - - - - - - - -	1125	1205	1528	1400
3.	Heat in decomposition of steam - - - - - - - - - - -	998	1100	763.0	912
4.	Heat contained in ash & refuse as sensible heat - -	Neglected			
5.	Heat lost in overflow from vaporizer - - - - - - - -	53.7	70	140	1495
6.	Heat lost in radiation and conduction. - - - - - - -	1371.	1824	1179	1286

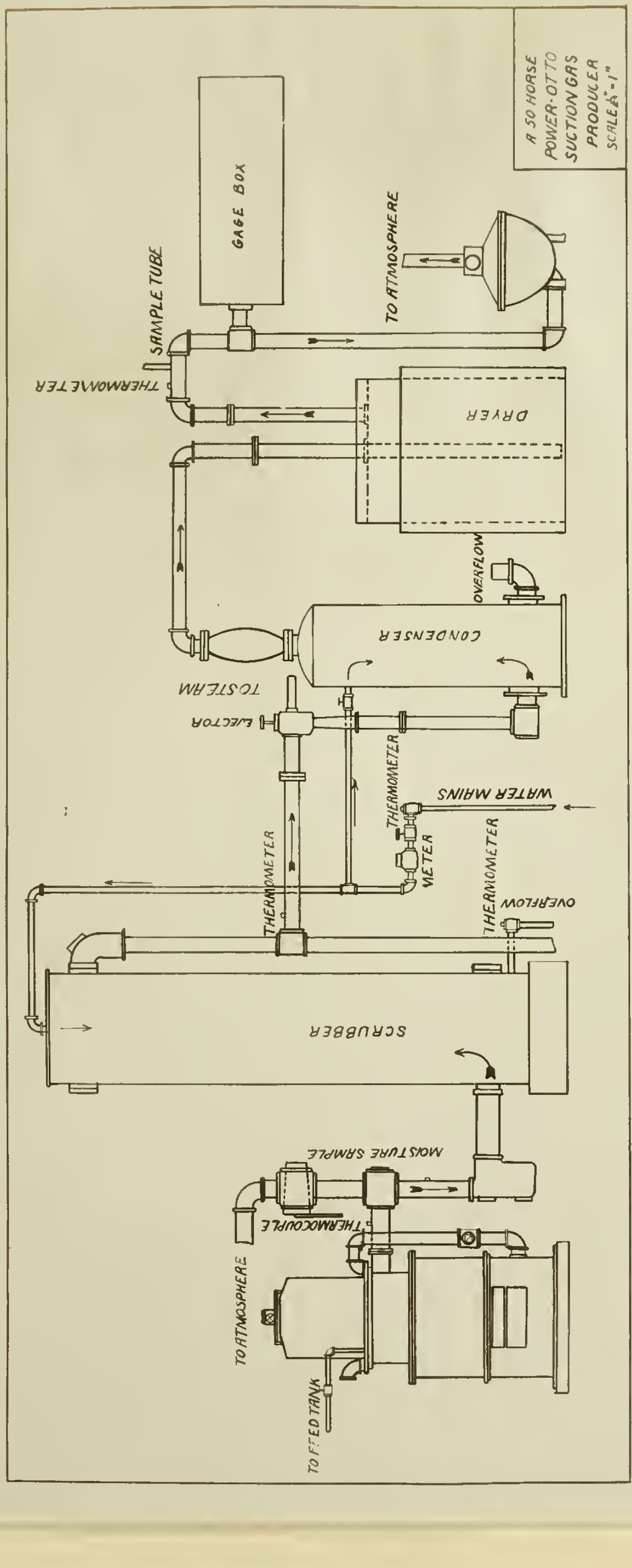
U. OF I. S. S. FORM 3


TEMP. GAS LEAVING PRODUCER
300 500 700 900 1100 1300
VOLUME OF GAS DISCHARGED
SCRUBBER WATER (LBS.)
2000 6000 10000 14000 18000 22000 26000 28000
B.T.U.
ROOM TEMP.
60 70 80 90 100 110
CO-H-CO_2
5 10 15 20
WATER USED IN VAPORIZER
50 100 150 200 250 300 350
12
1
2
3
4
5
6
7
8
8.30
ROOM TEMP.
B.T.U.
GAS TEMP.
H_2
CO_2
CO
SCRUBBER WATER
GAS
VAPORIZER WATER


TEMP. GAS LEAVING PRODUCER
400 600 800 1000 1200 1400
VOLUME OF GAS DISCHARGED
SCRUBBER WATER (LBS.)
4000 12000 20000 28000 36000 44000 52000 60000
B.T.U.
ROOM TEMP.
60 70 80 90 100 110
CO-H-CO_2
5 10 15 20
WATER USED IN VAPORIZER
100 200 300 400 500 600
10
11
12
1
2
3
4
5
6
6.30
ROOM TEMP.
B.T.U.
GAS TEMP.
H
CO_2
CO
SCRUBBER WATER
GAS
VAPORIZER WATER
U. OF I. S. S. FORM 3


TEMP. GAS LEAVING PRODUCER
300 500 700 900 1100 1300
VOLUME OF GAS DISCHARGED
SCRUBBER WATER (LBS.)
2000 6000 10000 14000 18000 22000 26000 30000
B.T.U.
ROOM TEMP.
70 80 90 100 110 120
CO - H - CO2
5 10 15 20
WATER USED IN VAPORIZER
50 100 150 200 250 300
10
11
12
1
2
3
4
5
6
6.45
ROOM TEMP.
B.T.U.
TEMP. GAS
H
CO2
CO
WATER
SCRUBBER
GAS
VAPORIZER WATER
U. OF I. S. S. FORM 3




A 50 HORSE
POWER-OTTO
SUCTION GAS
PRODUCER
GAGE BOX
SAMPLE TUBE
TO ATMOSPHERE
THERMOMETER
DRYER
OVERFLOW
CONDENSER
TO STEAM
EJECTOR
THERMOMETER
WATER MAINS
METER
THERMOMETER
THERMOMETER
OVERFLOW
THERMOMETER
SCRUBBER
MOISTURE SAMPLE
THERMOCOUPLE
TO ATMOSPHERE
TO FEED TANK